RESEARCH

Development and use of Site-Specific Chemical and Biological Criteria for Assessing New Bedford Harbor Pilot Dredging Project

WILLIAM G. NELSON*
DAVID J. HANSEN
US Environmental Protection Agency
Environmental Research Laboratory
27 Tarzwell Drive
Narragansett, Rhode Island 02882, USA

ABSTRACT / Numerical site-specific chemical and biological criteria were established to assess the impact of a pilot dredging project on water quality at the New Bedford Harbor, Massachusetts, USA, Superfund site. Because most existing chemical concentrations in the water column and indigenous biota exceeded federal and state water quality limits, the derivation of site-specific criteria was required. Prior to any operational phases of the project (i.e., dike construction, dredging), criteria values were developed from background concentrations of PCBs and metals in water and biota, as well as for the toxic effects of water quality on the biota. During each operational phase of the project, water samples were collected, analyzed within 16 h, and the data supplied to a management committee in order to assess the environmental impact of the previous days' operation. The ambient unfiltered water concentration of PCBs and metals were the only chemical or biological criteria exceeded. Modification of the next days' operations resulted in a return of these concentrations to background levels. The combined use of site-specific criteria and a real-time decision making management process allowed for successful completion of this project with a minimal effect on water quality.

Anthropogenic inputs to estuarine–marine waters have resulted in contaminated areas along the continental United States. Because of the contaminant concentrations in sediments, certain areas are listed on the Environmental Protection Agency's (EPA) National Priorities List (NPL) of hazardous waste sites scheduled for cleanup under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA 1980) and the Superfund Amendments and Reauthorization Act (SARA 1986). Dredging of contaminated sediments is one option often considered for remediation in marine waters. However, the possibility that sediments resuspended during dredging may be transported and contaminants released is always of concern. The magnitude of this transport and associated ecological risk can be quantified, and minimized, through an effective monitoring program and decision-making framework.

New Bedford Harbor (NBH), located along Buzzards Bay between the cities of New Bedford and Fairhaven, Massachusetts, USA, is scheduled for cleanup under authorization of the Superfund Act.

KEY WORDS: Decision-making; Real-time monitoring; Site-specific criteria; Dredging; PCBs; New Bedford Harbor; Superfund

*Author to whom correspondence should be addressed.

Over 18,000 acres of polychlorinated biphenyl (PCB) and heavy-metal-contaminated sediments have been identified, with PCB concentrations as high as 100,000 parts per milion (ppm) in some areas of the upper harbor (Weaver 1984). Because of the severe contamination in NBH, there is concern about the potential for unacceptable risks to public health and/or the environment that might be exacerbated by any remediation operation. Therefore, as a first step in the cleanup process, EPA Region I sponsored pilot studies to examine several remediation options (Allen and Ikalainen 1988). A pilot dredging study, designed by the US Army Corps of Engineers (COE), examined dredging and disposal options, continued disposal facility (CDF) and continued aquatic disposal (CAD), at this site (Averett and Francingues 1988, Otis and Averett 1988).

The goal of the NBH Pilot Dredging Project was to evaluate, in a small-scale field study, dredging technologies that could be used to remove and/or sequester contaminated sediments from NBH. A set of numerical criteria, based on biological and chemical monitoring, were considered necessary to serve as an early-warning mechanism that, if exceeded, would require a review of project operations. A decision then would be made concerning continuation, modification, or suspension of the project.

In this article we describe how site-specific decision criteria for the NBH Pilot Dredging Project were developed and implemented, and the decision-making process used to assess the environmental impact and manage the project. Subsequent articles will provide greater detail on the dredging operation and the results of the biological and chemical monitoring.

Methods

Criteria Rationale

Site-specific numerical criteria were required at this location because concentrations of many substances in the water, sediment, and biota of New Bedford Harbor exceeded existing state or federal action levels, criteria, or standards. For example, the national marine water quality criteria (WQC) concentration of 0.030 μg/liter for PCBs (US EPA 1980) was exceeded in 100% of 74 unfiltered and 25 filtered (0.45 μm) water samples collected during the year preceding the start of dredging (preoperational phase) of this project. The WQC of 2.9 μg/liter for copper (US EPA 1985a) and 5.6 μg/liter for lead (US EPA 1985b) were exceeded in 79% and 1%, respectively, of 71 preoperational unfiltered water samples. All samples analyzed for Cd were below the 9.3 μg/liter WQC (US EPA 1985c). Copper was the only one of the three metals measured that exceeded WQC concentrations in filtered water samples (32%).

In addition, criteria for this project could not be based on the accumulation of PCBs in seafood because concentrations in fish and shellfish indigenous to the harbor exceeded the 2 μg/g FDA action level (Kolek and Ceurvels 1981, Weaver 1984, Ryan and others 1988).

Finally, criteria could not be based solely on concentrations of a limited number of specific chemicals in water and sediments. The sediments to be dredged contain high concentrations of a variety of other chemical contaminants (Pruell and others 1990) and have been demonstrated to be toxic to amphipods (K. J. Scott, personal communication) and fish (W. J. Berry, personal communication). The observed toxicity may not be related solely to those chemicals monitored in the pilot dredging project. Therefore, it was necessary to develop both biological and chemical site-specific criteria based on conditions prior to initiation of this project.

Rationale for Station Location

The criteria established for the pilot study reflected the decision by the various managers involved in this project (Decision Criteria Committee) to accept the risk of moderate short-term increases in contaminants and associated bioaccumulation or toxicity in the near field (immediate vicinity of the dredging operation) provided no far-field effects were observed. With this objective in mind, strategic station locations were selected and decision criteria established for each.

While four stations were monitored during this project (Phelps and others 1988), only two were selected for use in the decision-making process based on their configuration and location. The Coggeshall St. Bridge (NBH-2) forms an opening about 30 m wide and separates the more contaminated upper estuary, including the pilot dredging site, from the lower harbor (Figure 1). Criteria were established at this station to restrict significant contaminant transport and excessive mortality to the lower harbor. A second constriction point, located at the NBH hurricane barrier (NBH-4), separated the harbor proper from the rest of Buzzards Bay (Figure 1). Criteria were established at this station to limit sublethal biological effects and specific contaminants from being transported out of NBH into Buzzards Bay. If criteria values were exceeded at the far-field station (NBH-4), they were not considered a result of the operation unless a corresponding impact was observed at the near-field station (NBH-2).

The criteria at each of these stations were established using preoperational chemical and biological monitoring data. While water samples were collected on both incoming (flood) and outgoing (ebb) tides, criteria were established only for ebb tides because contaminants present during this tidal phase would potentially contribute the most to down-harbor impacts.

Preoperational Monitoring Methods

The preoperational monitoring data included measurement of PCBs, Cu, Cd, and Pb in the water column and in tissues of the blue mussel, *Mytilus edulis*. Biological effects measured included the acute and chronic toxicity on marine and estuarine species using toxicity tests developed for the US EPA Complex Effluent Toxicity Testing Program (Weber and others 1988) and scope for growth in mussels (Nelson and others 1987).

Concentrations of PCBs (quantified as the total of Aroclors 1242 and 1254), Cu, Cd, and Pb were determined in unfiltered water samples collected prior to project initiation on consecutive ebb and flood tides on eight days between July 1987 and June 1988. Equal volumes of water collected 1 m below the surface, middepth, and 1 m above the bottom were composited each hour during the ebb and flood tides at the hurricane barrier, NBH-4 (Figure 1). Hourly ebb and flood water samples collected at the Coggeshall St. Bridge, NBH-2, were flow-proportionately composited from three depths and two horizontal locations. Bioaccumulation of PCBs in mussel tissue also was measured after

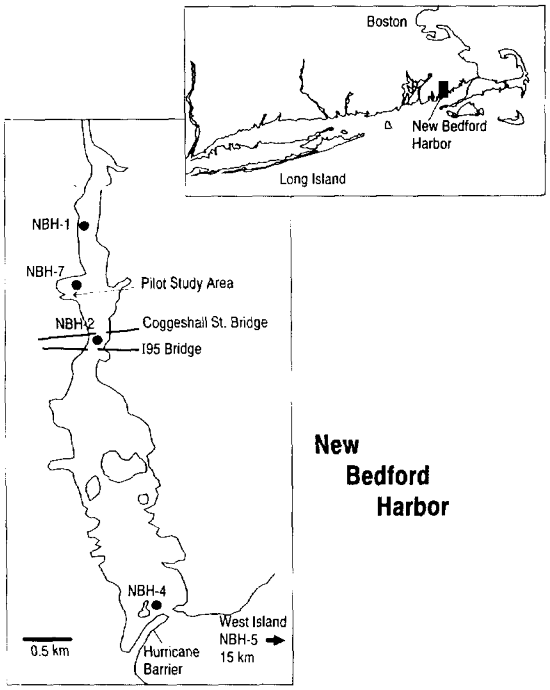

Figure 1. Map of New Bedford Harbor indicating the location of the pilot study area and the stations used in the decision criteria (Coggeshall St. Bridge, NBH-2, and the hurricane barrier, NBH-4). The reference station (NBH-5) is located 15 km east of New Bedford Harbor at West Island.

two seven- and 28-day deployments at these two stations.

The biological criteria were based on data collected during the preoperational phase of this project and the "best professional judgement" of the investigators at ERL-N who previously had developed and/or applied these tests. This approach was necessary because a limited number of biological tests were conducted during the preoperational phase. Each principal investigator was asked to determine what magnitude of change in their respective end point, compared to a reference site, has been demonstrated to constitute a statistically real difference based on tests completed at a number of Atlantic and Gulf Coast locations. This approach resulted in a potentially better estimate of the variability associated with these tests than the limited number of biological samples collected during the preoperational phase of the project.

The methods for the biological tests used in this study are summarized by Weber and others (1988). An aliquot of the water composited at each station was returned to ERL-N, where toxicity tests were conducted. At NBH-2, biological responses used in the decision criteria included the mortality associated with exposure of the red alga, *Champia parvula,* mysid, *Mysidopsis bahia,* sheepshead minnow, *Cyprinodon variegatus,* to ebb-tide seawater composites and mussels deployed in situ. The percentage of fertilized eggs in the sea urchin, *Arbacia punctulata,* was used also because of the sensitivity and speed of this test. At NBH-4, seven-day tests were used to assess the sublethal impact of composite water samples on growth and reproduction in the mysid and growth in the sheepshead minnow. Three-day tests were employed to assess reproductive effects (cystocarp production) in the red alga. In addition, scope for growth (Nelson and others 1987) was measured in mussels deployed for seven and 28 days at both stations.

Chemical Decision Criteria

The concentration that constituted an "unacceptable" increase for chemical contaminants was established as a statistically significant ($\alpha = 0.01$) increase over preoperational baseline concentrations (Table 1). This level of significance was selected to ensure that random events (5% of the time at $\alpha = 0.05$) did not shut down the operation unnecessarily.

Preoperational chemical concentrations of PCBs, Cu, Cd, and Pb in water and bioaccumulation of PCBs by mussels used to calculate decision criteria values were logarithm-transformed because chemical monitoring data are typically log-normally distributed. Decision criteria values were established according to the t test for comparison of single observations with the mean of a sample ($\alpha = 0.01$) (Sokal and Rohlf 1969, p. 224). This allowed testing of the null hypothesis that a single daily sample was not different from the preoperational mean. The decision criterion value for cadmium employed in this study (9.3 μg/liter) was from the water-quality criteria document (US EPA 1985c) because this concentration was greater than the statistically based value.

Biological Decision Criteria

The values that constituted an unacceptable biological impact were qualitatively and quantitatively different for stations NBH-2 and NBH-4. The objective of the criteria at NBH-2, the delineation between the upper and lower harbor, was to prevent the discharge of water that could be lethal to organisms in the lower harbor, while allowing some sublethal effects. The purpose of the criteria at NBH-4, the boundary between the harbor and Buzzards Bay, was to limit transport out of the harbor of waterborne contaminants that might cause sublethal biological effects on growth and reproduction. The point of comparison for both acute and sublethal effects was a reference site located at West Island (NBH-5) in Buzzards Bay (Figure 1).

Table 1. Preoperational chemical monitoring data and corresponding decision criteria values

End point	Coggeshall St. Bridge (NBH-2) Preoperational data $\bar{X}$ (N)[b]	CV[c]	Decision[a] criteria	Hurricane Barrier (NBH-4) Preoperational data $\bar{X}$ (N)	CV	Decision[a] criteria
Water chemistry (μg/liter)						
PCBs	0.60 (8)	53	1.4	0.11 (7)	19	0.44
Cadmium	0.23 (8)	22	9.3[d]	0.12 (8)	30	9.3[d]
Copper	5.3 (8)	17	13	2.5 (8)	30	6.0
Lead	2.6 (8)	33	7.2	2.1 (8)	82	15
PCB bioaccumulation (*Mytilus edulis*, μg/g dry weight)						
7 days	46 (7)	21	80	7.1 (7)	49	19
28 days	95 (6)	18	160	14 (7)	21	23

[a]Violation of these values required an action prior to continuation of the project.

[b]Mean value and number of samples used to calculate it.

[c]Coefficient of variation.

[d]Decision criterion for cadmium is the criteria continuous concentration from the water quality criteria document (US EPA, 1985a)

Arcsine transformations were performed on the acute mortality data prior to the calculation of means, variances, and critical values.

The following decision criteria values were recommended as appropriate for limiting short-term biological impact at station NBH-2: test mortality greater than 20% of that at the reference site (NBH-5) for any two species, or mortality 50% greater than at the reference site for any single species (Table 2). The criteria at station NBH-4 were derived similarly. The exceeding of biological criteria for any two species, or by a factor of two for any one species, was considered a violation of the decision criteria (Table 2).

Decision-making Framework

A management panel, the Decision Criteria Committee, was established to review monitoring data and determine necessary actions if decision criteria values were exceeded during the operational phases of the project. The committee included representatives from EPA Region I, the US Army Corps of Engineers-New England Division, EPA's Environmental Research Laboratory, Narragansett, Rhode Island (ERL-N), the Massachusetts Department of Environmental Quality and Engineering, and the Massachusetts Department of Coastal Zone Management. The procedure for deriving decision criteria and the appropriate numerical values were fixed prior to initiation of the operational phases of the project: dike construction and dredging (Otis and Averett 1988). Chemical and acute biological monitoring data were transmitted to the committee daily. If any criteria values were exceeded, the next day's operations were halted until the committee decided on an appropriate action. Options included, but were not limited to, the following: confirm the reasonableness of observations relative to monitoring data from other stations in this study, increase monitoring, modify the operation (i.e., install silt curtains, change dredges, change dredging operational procedures, etc.), or terminate the project.

The key to the decision-making process employed in this project was that data had to be available in a very short time frame so that any potentially unacceptable chemical or biological impacts could be detected rapidly and appropriate actions taken. Because of the shallow depth of the pilot study area (less than 0.5 m at low tide), and the restriction of dredging operations to the daylight hours, dredging began approximately 2 h before and ended 2 h after daylight high tides. The collection and analysis of most chemical and biological effects data on ebb tide composites from stations NBH-2 and NBH-4 had to be completed prior to resumption of the next day's dredging so that these data could be compared to the decision criteria values and a determination of environmental impact made. Therefore, chemical and sea urchin fertilization data were made available to the Decision Criteria Committee at least 1 h before the start of that day's operation, approximately 16 h after collection.

Other acute biological data (mortality of mysids,

Table 2. Preoperational biological monitoring data and the corresponding decision criteria values

Species	Response	Preoperational data: Mean	Standard deviation	Number samples	Decision[a] criteria
Coggeshall Street Bridge (NBH-2) (acute responses)					
Red alga, *Champia parvula*	Survival (%)	100 [100][b]	0 [0]	2 [2]	20% (50%)
Blue mussel, *Mytilus edulis*	Survival (%)	95 [99]	24 [14]	5 [7]	20% (50%)
Sea urchin, *Arbacia punctulata*	Fertilization (%)	93 [94]	4 [3]	12 [11]	20% (50%)
Mysid, *Mysidopsis bahia*	Survival (%)	100 [99]	0 [15]	8 [8]	20% (50%)
Sheepshead minnow, *Cyprinodon variegatus*	Survival (%)	88 [93]	5 [10]	6 [6]	20% (50%)
Hurricane Barrier (NBH-4)					
Red alga,[c] *Champia parvula*	Cystocarps (N)	18	5.1	30	50% (100%)
Blue mussel,[d] *Mytilus edulis*	Scope for growth (J/h)	1.3	2.3	4	7.5 (15)
Sea urchin, *Arbacia punctulata*	Fertility (%)	93 [94]	4 [3]	12 [11]	25% (50%)
Mysid, *Mysidopsis bahia*	Dry weight (mg)	0.28 [0.29]	0.02 [0.02]	8 [8]	20% (40%)
Sheepshead minnow, *Cyprinodon variegatus*	Dry weight (mg)	1.2 [1.1]	0.1 [0.1]	6 [6]	20% (40%)

[a]Station NBH-2: survival, or percent fertilization in sea urchins, less than 20% of the reference station for any species, or 50% for any one species. Station NBH-4; reduction of any two parameters by the amount indicated, relative to the reference station, or reduction of any single parameter by the amount shown in parentheses.

[b]Biological responses at the West Island reference station (NBH-5) are shown in brackets.

[c]Values shown are representative of control treatment response at numerous locations during the past year.

[d]Values represent the relative differences between stations NBH-4 and NBH-5.

fish, red alga, and mussels) were available within 48 h of collection. Bioaccumulation data were to be completed before the start of the next phase of the operation, as were the results of the sublethal biological tests. This approach was appropriate because the probability of environmental risk was projected to increase with each progressive phase of the project.

Results and Discussion

This discussion will focus on the effectiveness of this approach to: (1) establish site-specific criteria based on background (i.e., preoperational) monitoring data, (2) detect significant elevations of contaminants during the operational phases of the project, (3) identify the causes of the increases, and (4) reduce elevations through the modification of operational procedures, thus allowing the project to be completed.

Preoperational Monitoring

Water and mussel tissue chemistry data collected during the preoperational phase at stations NBH-2 and NBH-4 are presented in Table 1. The mean, number of samples, coefficient of variation, and decision criteria values are listed for each parameter.

Preoperational biological monitoring showed no statistically significant ($\alpha = 0.01$) reductions in survival, growth, or reproduction of algae, sea urchins, mysids, or fish exposed to water from stations NBH-2 and NBH-4 relative to the West Island reference station, NBH-5 (Table 2). There were no significant differences in mortality between stations NBH-2 and NBH-5 for deployed mussels. In addition, growth and scope for growth of mussels deployed at station NBH-4 did not differ from those mussels deployed at NBH-5 on any preoperational sampling date.

Operational Monitoring

The chemical criteria values were exceeded on three occasions due to elevated PCB concentrations at NBH-2, once due to elevated PCB, Cu, and Pb concentrations at NBH-2 (Figure 2), and once due to elevated Cu concentrations at NBH-4. These elevations

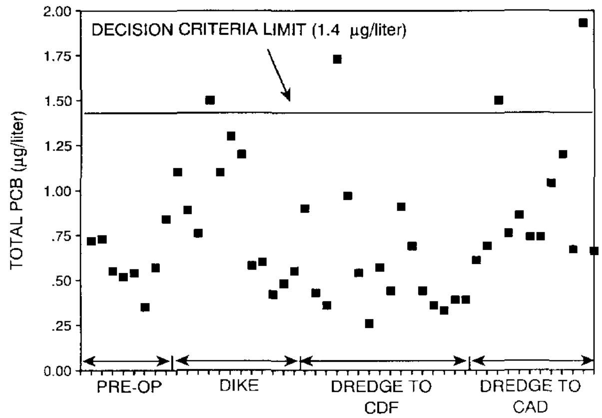

Figure 2. Graph of PCB concentrations (µg/liter) in whole water samples collected on the ebb tide at station NBH-2 during the New Bedford Harbor Pilot Dredging Project. Violation of the PCB decision criterion value (≥1.4 µg/liter) occurred once each during the dike construction and CDF dredging phases, and twice during the CAD operation. The dates associated with each sampling phase of the project include: preoperational July 9, 1987 to June 15, 1988; dike construction June 20, 1988 to November 10, 1988; dredge to the CDF November 11, 1988 to December 29, 1988; and dredge to CAD January 1, 1989 to February 3, 1989.

were not greater than a 35% increase over decision criteria values; mean increase was 13%.

The initial violation of the chemical criteria (1.5 µg PCB/liter) occurred during construction of the in-water portion of the dike for the CDF. A geotechnical fabric was placed in the water on top of contaminated sediment as a base for the dike. Fill was placed onto the fabric starting onshore and moving out into the water (Otis and Averett 1988). As this occurred, sediment was pushed ahead of the fill creating a mound ("mud wave") underneath the fabric. It is believed that observed increases in contaminant concentrations were caused by the release of interstitial water and/or the release of contaminants associated with previously anoxic subsurface sediments upon exposure to oxygenated overlying water as a result of this movement of mud. This dike construction procedure was modified by placement of fill on the edges of the fabric first during subsequent construction. As a result, PCB concentrations returned to near background (0.58 µg/liter) and remained low throughout the remainder of this phase of the project.

The second violation of the PCB criterion value, (1.7 µg/liter) was accompanied by an exceeding of the criteria values for Cu (13 µg/liter) and Pb (7.6 µg/liter). These elevated contaminant concentrations occurred during a severe rainstorm with 40-knot winds. Normally, the depth of the upper estuary is less than 1 m during typical low tides; however, this storm event coincided with extra low tides exposing highly contaminated sediments in the upper harbor. It is probable that the combined effect of rain, wind, and tide resulted in resuspension of the contaminated sediments and elevated the PCB, Cu, and Pb concentrations at NBH-2. The strong evidence of a weather-induced event, as opposed to an operational one, suggested that no modification of the operation was necessary. Additional monitoring the following day revealed that the concentrations of PCBs, Cu, and Pb in water returned to below the criteria limits (0.97, 3.3, and 2.1 µg/liter, respectively).

The third violation of the PCB criterion value (1.5 µg/liter) occurred during dredging to the CDF with a "matchbox" dredge (Otis and Averett 1988). This particular dredge operates by channeling sediment into the dredgehead as it moves. It is believed that the dredgehead was cutting too deep, thus tunneling under the surface of the sediment instead of burrowing through it. This may have caused resuspension of surficial sediments, exposure of subsurface anoxic sediment, and a release of contaminants (similar to that postulated during dike construction). Modification of the dredgehead cutting depth the next day was followed by a decrease of the PCB concentration to 0.78 µg/liter. Maintenance of proper cutting depths resulted in no other instances of elevated PCB concentrations during the operation of this dredge.

The final violation of the PCB decision criterion at NBH-2 (1.9 µg/liter) occurred during capping of the CAD. Dredged material was placed into the CAD via an underwater diffuser. This device normally was located next to the bottom of the CAD during the capping operation. On the day when the criterion was exceeded, the diffuser had been placed too close to the surface of the water, allowing sediment to be suspended into the water column rather than settling into the CAD. Placement of the diffuser nearer to the bottom of the CAD was followed by a return of PCB concentrations to background levels (0.66 µg/liter).

Demonstration of the effectiveness of the real-time monitoring/decision-making process during the operational phases of the project was the fact that each of four violations of decision criteria values were apparently attributable to specific climatological events or operational procedures. Additionally, modification of those procedures was associated with a return of contaminant concentrations to below the criteria values, which allowed for a continuation of the project.

There was only one instance where a chemical criterion value was elevated at station NBH-4. The concentration of Cu was 8.07 µg/liter, exceeding the criterion value of 6.0 μg/liter. No parallel elevation in Cu concentration was observed at NBH-2. Therefore, the increase at NBH-4 was not attributed to any operational event, the decision criteria were not violated, and a committee response was not required.

While the chemical criteria were exceeded on several occasions, there were no corresponding violations of the biological criteria (Table 2). Although there may have been no adverse effects to observe, it is also possible that the biological monitoring methods were not sensitive. We believe the former is true. The mean unfiltered water chemical concentrations at NBH-2 during operational phases (i.e., PCBs = 0.81 μg/liter, N = 36) were similar to those during the preoperational data (PCBs = 0.60 μg/liter). Similarly, PCB concentrations in mussels at NBH-2 were almost identical after seven-day preoperational (46 μg/g) and operational (dike construction and CDF dredging) deployments (48 μg/g). Therefore, chemical data suggest that exposures were not elevated and biological effects would not be expected. Furthermore, biological and chemical analyses of water collected immediately adjacent to the dredging site suggests that the biological tests were sensitive. Adverse biological effects were observed in *A. punctulata, C. parvula*, and *M. bahia* (G. Morrison, personal communication) immediately adjacent to the dredging site, where the mean PCB concentration was 1.43 μg/liter, nearly a two-fold increase relative to NBH-2.

We conclude that biological and chemical monitoring methods were sensitive and demonstrated the absence of significant additional risks associated with this pilot dredging project. This conclusion is supported by: (1) the lack of biological effects at NBH-2 and NBH-4 during preoperational and operational phases of the project, (2) the detection of biological effects immediately adjacent to the operation associated with elevated contaminant concentrations, (3) the absence of consistent elevations in chemical concentrations at NBH-2 and NBH-4 during the operation relative to preoperational values, and (4) the detection of episodic increases in chemical concentrations associated with specific operational events. When these episodic chemical violations did occur, they were detected immediately, the operational procedure modified, and concentrations always returned to near background the following day. Therefore, by using this real-time monitoring/decision-making framework, contaminant concentrations were maintained below those that might cause significant biological impacts detectable by these toxicity tests. Thus, one of the ultimate goals of this project was realized: to limit ecological risks associated with the project.

Conclusions and Recommendations

The NBH project was developed as a pilot study. As such, it was used to test a "real-time" monitoring/decision-making approach for assessing the environmental risks associated with a potentially adverse dredging operation. We believe that these procedures were acceptable and useful in this project and that the concept is applicable at other locations. However, the actual site-specific decision criteria values developed for NBH should not be employed at other sites. Such criteria, of necessity, must be tailored to fit other site-specific needs.

The coupling of chemical and biological monitoring proved to be particularly important. No significant biological effects in any test or bioaccumulation in mussels were observed during this project because the duration of chemical violations was limited as a result of modification of operational procedures. This contributed to the objective of the project: to complete the pilot dredging operation with no "unacceptable" environmental risks.

Finally, the joint participation of individuals from federal and state agencies in all aspects of the project (i.e., development of decision criteria, participation on Decision Criteria Committee, etc.) was invaluable. An atmosphere of cooperation prevailed during the pilot dredging project and facilitated its successful completion.

In summary, we believe that the development and use of decision criteria, coupled with real-time monitoring, was valuable for: (1) identifying operational problems during the project, (2) improving operational procedures in a timely manner, and (3) limiting probable risks associated with the project. This approach is recommended for similar applications during other remediation projects where highly contaminated, toxic sediments are present.

Acknowledgments

The authors thank the many individuals who participated in this project, including Frank Ciavattieri (EPA Region I), Mark Otis (US Army Corps of Engineers), and especially the dedicated federal (Donald Phelps, ERL-N Project Manager) and SAIC (K. John Scott, Contract Manager) personnel at ERL-N who sampled, processed, and analyzed the data contained within this manuscript. We also thank the three technical reviewers for their comments on this manuscript. This paper is contribution 1090 from ERL-N.

Literature Cited

Allen, D. C., and A. J. Ikalainen. 1988. Selection and evaluation of treatment technologies for the New Bedford Harbor (MA) superfund project. Pages 329–334 *in* Proceedings of the 9th Annual Conference, The Hazardous Waste Control Institute, 28–30 November 1988. Washington, DC.

Averett, D. E., and N. R. Francingues, Jr. 1988. A case study: Dredging as a remedial action alternative for New Bedford Harbor, Massachusetts. Pages 338–342 *in* Proceedings of the 9th Annual Conference, The Hazardous Waste Control Institute, 28–30 November 1988. Washington, DC.

CERCLA (Comprehensive Environmental Response, Compensation, and Liability Act) 1980. Public Law 96-510. 42 US Congress 9601-9657. 11 December 1980.

Kolek, A., and R. Ceurvels. 1981. Polychlorinated biphenyl (PCB) analysis of marine organisms in the New Bedford area, 1976–1980. 29 pp. in Commonwealth of Massachusetts, Division of Marine Fisheries. Publication No. 12265-36-100-1-81-CR.

Nelson, W. G., D. K. Phelps, W. B. Galloway, P. F. Rogerson, and R. J. Pruell. 1987. Effects of Black Rock Harbor dredged material on the scope for growth of the blue mussel, *Mytilus edulis,* after laboratory and field exposures. Technical Report D-87-7, prepared by the US Environmental Protection Agency, Environmental Research Laboratory, Narragansett, Rhode Island for the US Army Engineers Waterways Experiment Station, Vicksburg, Massachusetts. 116 pp.

Otis, M. J., and D. E. Averett. 1988. Pilot study of dredging and dredged material disposal methods, New Bedford, Massachusetts superfund site. Pages 347–352 *in* Proceedings of the 9th National Conference, The Hazardous Waste Control Institute, 28–30 November 1988. Washington, DC.

Phelps, D. K., D. J. Hansen, K. J. Scott, and A. S. Fowler. 1988. Monitoring program in support of the pilot study of dredging and dredged material disposal methods, New Bedford, Massachusetts superfund site. Pages 335–337 *in* Proceedings of the 9th National Conference, The Hazardous Materials Control Institute, 28–30 November 1988. Washington, DC.

Pruell, R. J., C. B. Norwood, R. D. Bowen, W. S. Boothman, P. F. Rogerson, M. Hackett, and B. C. Butterworth. 1990. Geochemical study of sediment contamination in New Bedford Harbor, Massachusetts. *Marine Environmental Research* 29:77–101.

Ryan, E. A., M. A. Donato, S. L. Santos, and J. A. Buries. 1988. Public health and environmental risk assessment for the New Bedford Harbor Superfund site. Pages 353–358 *in* Proceedings of the 9th National Conference, The Hazardous Materials Control Institute, 28–30 November 1988. Washington, DC.

SARA (Superfund Amendments and Reauthorization Act of 1986). 1986. Public Law 99-499. US Congress.

Sokal, R. R., and J. F. Rohlf. 1969. Biometry: The principals and practice of statistics in biological research. W. H. Freeman and Co., San Francisco, California. 776 pp.

US EPA. 1980. Ambient water quality criteria for polychlorinated biphenyls. EPA 440/5-80-068. 197 pp.

US EPA. 1985a. Ambient water quality criteria for copper—1984. EPA 440/5-84-031. 142 pp.

US EPA. 1985b. Ambient water quality criteria for lead—1984. EPA 440/5-84-027. 87 pp.

US EPA 1985c. Ambient water quality criteria for cadmium—1984. EPA 440/5-84-032. 136 pp.

Weaver, G. 1984. PCB contamination in and around New Bedford, Massachusetts. *Environmental Science and Technology* 18(1):22A–27A.

Weber, C. I., W. B. Horning, D. J. Klemm, T. W. Neiheisel, P. A. Lewis, E. L. Robinson, J. Menkedick, and F. Kessler. 1988. Short-term methods for estimating the chronic toxicity of effluents and receiving waters to marine and estuarine organisms. EPA 600/4-87-028. May 1988. 417 pp.